

A FIB/TEM STUDY OF A COMPLEX WARK-LOVERING RIM ON A VIGARANO CAI. L. P. Keller¹, A. W. Needham² and S. Messenger¹. ¹Robert M. Walker Laboratory for Space Science, Code KR, ARES, NASA/JSC, Houston, TX 77058. ²LPI, 3600 Bay Area Blvd., Houston, TX 77058. Lindsay.P.Keller@nasa.gov

Introduction: Wark-Lovering (WL) rims are thin multi-layered mineral sequences that surround most Ca, Al-rich inclusions (CAIs). Several processes have been proposed for WL rim formation, including condensation, flash-heating or reaction with a nebular reservoir, or combinations of these [e.g. 1-7], but no consensus exists. Our previous coordinated transmission electron microscope (TEM) and NanoSIMS O isotopic measurements showed that a WL rim experienced flash heating events in a nebular environment with planetary O isotopic composition, distinct from the ¹⁶O-rich formation environment [6]. Our efforts have focused on CAIs from the CV_{red} chondrites, especially Vigarano, because these have escaped much of the parent body alteration effects that are common in CAIs from CV_{ox} group.

Results and Discussion: We studied a fragment of a CAI with a complex multi-layered WL rim from the Vigarano CV3 chondrite using scanning electron microscopy (SEM) and electron microprobe analysis. The core of the inclusion contains abundant fine-grained hibonite needles, with lesser spinel and perovskite grains. The WL rim consists of 7 distinct layers in the following sequence: (1) an innermost spinel (Sp₈₉Hc₁₁)-hibonite layer, (2) a gehlenite layer (Ak₀), (3) a thin layer of anorthite (An₉₉) admixed with minor spinel at its base, (4) a layer of zoned Ca-pyroxene (Al-rich at the base, Wo₅₀En₅₀ at the top), (5) a layer showing a symplectic intergrowth of forsterite (Fo₉₉) and diopside, (6) a thin Fe-bearing diopside layer, and (7) an outermost thin Fe-bearing forsterite (Fo₉₅) layer.

We prepared thin sections of the WL rim using a focused ion beam (FIB) instrument and examined the sections in the TEM. Layers 1-6 are polycrystalline and show equilibrium (120°) grain boundaries. Planar defects along (111) occur in some of the spinels. Gehlenite contains numerous planar defects along (001). Twinning is present in the anorthite and diopside. The forsterite in layer 7 is polycrystalline, but displays a columnar morphology with a common growth direction for many crystals. The outermost surfaces of the columnar forsterite grains are decorated with tiny epitaxial grains of a chromite-spinel solid solution.

Conclusions: Given the paucity of Mg- and Si-bearing phases in the CAI interior, nearly all of the Si and much of the Mg and Ca in the rim were likely derived from a nebular reservoir rather than by alteration of the host CAI. Equilibrium grain boundaries present in layers 1-4 are consistent with annealing of condensates at high temperatures. The symplectic intergrowth in layer 5 may have a melt origin. The morphology of the columnar forsterite grains in layer 7 is consistent with vapor phase growth. These observations show that the WL rim formed by multi-stage condensation and heating events. Coordinated NanoSIMS O isotopic imaging of the WL rim are planned to constrain its history of interactions with nebular reservoirs.

References: [1] Wark D.A. and Lovering J.F. (1977) *LPS* 8, 95. [2] MacPherson G.J. (2004) *Treatise on Geochemistry*, 201. [3] Simon J. I. et al. (2005) *EPSL*, 238, 272. [4] Wark D. and Boynton W. (2001) *MAPS*, 36, 1135. [5] MacPherson G.J. et al. (1981) *LPS* 12, 648. [6] Ito, M. et al. (2010) *LPS* 41, #1177. [7] Simon, J. L. et al. (2011) *Science* 331, 1175.